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# INVESTIGATIONS OF HEAT CANKER OF FLAX.[1]

By C. S. Reddy and W. E. Brentzel, *Assistant Pathologists, Office of Cereal Investigations, Bureau of Plant Industry.*



CONTENTS.



## INTRODUCTION.

The seed-flax area of the United States coincides closely with the spring-wheat region of the Northwest, composed for the most part of the States of Minnesota, the Dakotas, and Montana. Within this area flax wilt, drought, and weeds are the most important limiting factors in flax production. Flax wilt has gradually pushed the center of flax production westward into uninfested areas, while the newly broken prairie sod with its absence of weeds has led it in the same direction. When the production of flax reached this semiarid section, complaints came from the growers that the plants often broke over at or near the surface of the soil, as though whipped off by the winds or gnawed by insects.

Fortunately for flax production, Prof. H. L. Bolley early became its advocate in North Dakota and devoted the greater part of his time to it for a number of years. He found the cause of flax wilt and developed control measures in the form of seed selection, seed treatment, and the development of resistant varieties (*1*, *2*, *3*, and *4*).[2] This has helped to eliminate losses from diseases caused by parasitic seed-borne organisms. Further work (*4* and *5*) explained the cause of one type of flax canker. As this disease was very destructive in

[1] The investigations here reported have been conducted in cooperation with the department of plant pathology of the North Dakota Agricultural Experiment Station. The writers wish to acknowledge their indebtedness to Prof. H. L. Bolley for many helpful suggestions in the progress of the work and to Dr. A. G. Johnson for assistance in the preparation of the manuscript.

[2] The serial numbers (italic) in parentheses refer to "Literature cited" at the end of this bulletin.

western North Dakota and eastern Montana, arrangements were made with the United States Department of Agriculture to continue the flax-canker investigations as a cooperative project. This paper deals with the results obtained under this cooperation, which began in 1916.

Flax canker is a term which has been applied to any injury to flax which causes it to break over at or near the soil line. However, the symptoms are not always identical in different districts or in different years. Explanations of all these symptoms have not been obtained.

## ANTHRACNOSE CANKER.

Anthracnose canker was described by Bolley in 1910 (*4* and *5*), when he assigned *Colletotrichum lini* as the cause. Schoevers, in Holland (*19*), dealt with the same disease and fungus in 1915. Pethybridge and Lafferty (*15* and *16*) identified this disease in Ireland, and in 1918 they named the causative organism *Colletotrichum linicolum*. They stated that the priority of *Colletotrichum lini* Bolley was not recognized because of inadequate description. T. Hemmi in 1920 (*9*) described this disease in Japan and stated that a species of Colletotrichum was isolated which when used to inoculate young plants produced a seedling blight with typical anthracnose lesions.

In 1916 a species of Colletotrichum was isolated from flax seed of a number of varieties grown at Mandan, N. Dak., in 1915. In inoculation experiments it proved to be parasitic on flax seedlings and produced what properly could be called a damping-off seedling disease (Pl. I).

Surveys of the seed-flax area, extending over a period of six years, gave evidence that different types of flax canker are widespread and capable of producing economic loss and in isolated cases are capable of destroying whole fields of flax. Strange to say, during these six years anthracnose canker was not found by the writers in the seed-flax area, with one exception, when it was discovered on young flax about an inch and a half high at Grassrange, Mont., in 1917.

At the request of the flax-fiber specialist in the Office of Fiber-Plant Investigations a disease survey of the fiber-flax districts of Michigan and Wisconsin was made during the summer of 1920. Anthracnose canker was found to be widespread in the Michigan district. In a number of cases flax beyond the seedling stage was affected. In some instances as many as 60 per cent of the plants showed girdling, with anthracnose lesions in connection with the girdled areas. This condition closely resembled what Bolley described in 1910 and 1912 (*4* and *5*). The indications are that it is probably a combination of injuries caused by heat and parasitic fungi. The area affected may be determined more by temperature and the resulting physiological effect on the cells than by moisture, oxygen,

or light relations; but under the Michigan conditions few of the plants toppled over, and in the moist latter half of the season there was almost complete recovery. Anthracnose canker seems to be rather rare in the United States during some years, and when present its damage is confined almost entirely to young seedlings.

## HEAT CANKER OF FLAX, A NONPARASITIC TYPE.

This type of flax canker, according to continuous studies since 1916 reported by the writers in 1920 (*18*), causes severe losses and occurs to about the same extent each year in the semiarid flax-producing section of the United States. It is most evident during the latter half of June and the first half of July. The outside portion of the stem is killed at or near the surface of the ground when the plants are comparatively young (Pl. II, A and B; Pl. III, A and B).

Generally speaking, if the injury occurs when the plants are less than 3 inches in height the tissues collapse at the point of injury and the plants wither and die (Pl. III, A and B; Pl. IV, A to D). If the injury occurs somewhat later, when the plants are 3 to 5 inches in height, only the cortex is killed, allowing the plants to topple over, but usually to remain alive for days or weeks because of the uninjured vascular systems within (Pl. II, A and B; Pl. V, A to C). Only in rare instances are plants more than 5 inches in height injured in this way. Numerous more mature specimens of heat-cankered flax can be found, but in such cases growth continues after the initial injury. Enlargement of the stem occurs just above and sometimes just below the injury (Pl. II, A and B; Pl. V, A to C). In most cankered plants the stem is severed, sooner or later, at the point of girdling by the winds or by the disintegration of the remaining tissues, due to the action of saprophytic organisms. Otherwise the plant dies when the starving roots can no longer support the increasing needs of the aerial portion. For this type of canker the name "heat canker of flax" is suggested.

In order to avoid confusion, it may be well to state here that the nonparasitic flax canker discussed in this paper does not include a type which occurs late in the season in the driest districts of the northern Great Plains area. Following drought the base of the stem becomes very woody, dry, and brittle, with little tensile strength, and is snapped off by the wind. This trouble also seems to be nonparasitic in its nature.

## CAUSE OF HEAT CANKER.

### ISOLATIONS AND PATHOGENICITY EXPERIMENTS.

Hundreds of isolations from cankered specimens of this type resulted sometimes in the growth of no organisms at all and never in the constant association of any one organism with the disease.

Numerous inoculations with fungi and bacteria from these isolations always failed to produce symptoms identical with those of the type of flax canker under consideration. Hence, this preliminary work indicated more and more clearly that this type of flax-canker injury was due to causes of a nonparasitic nature.

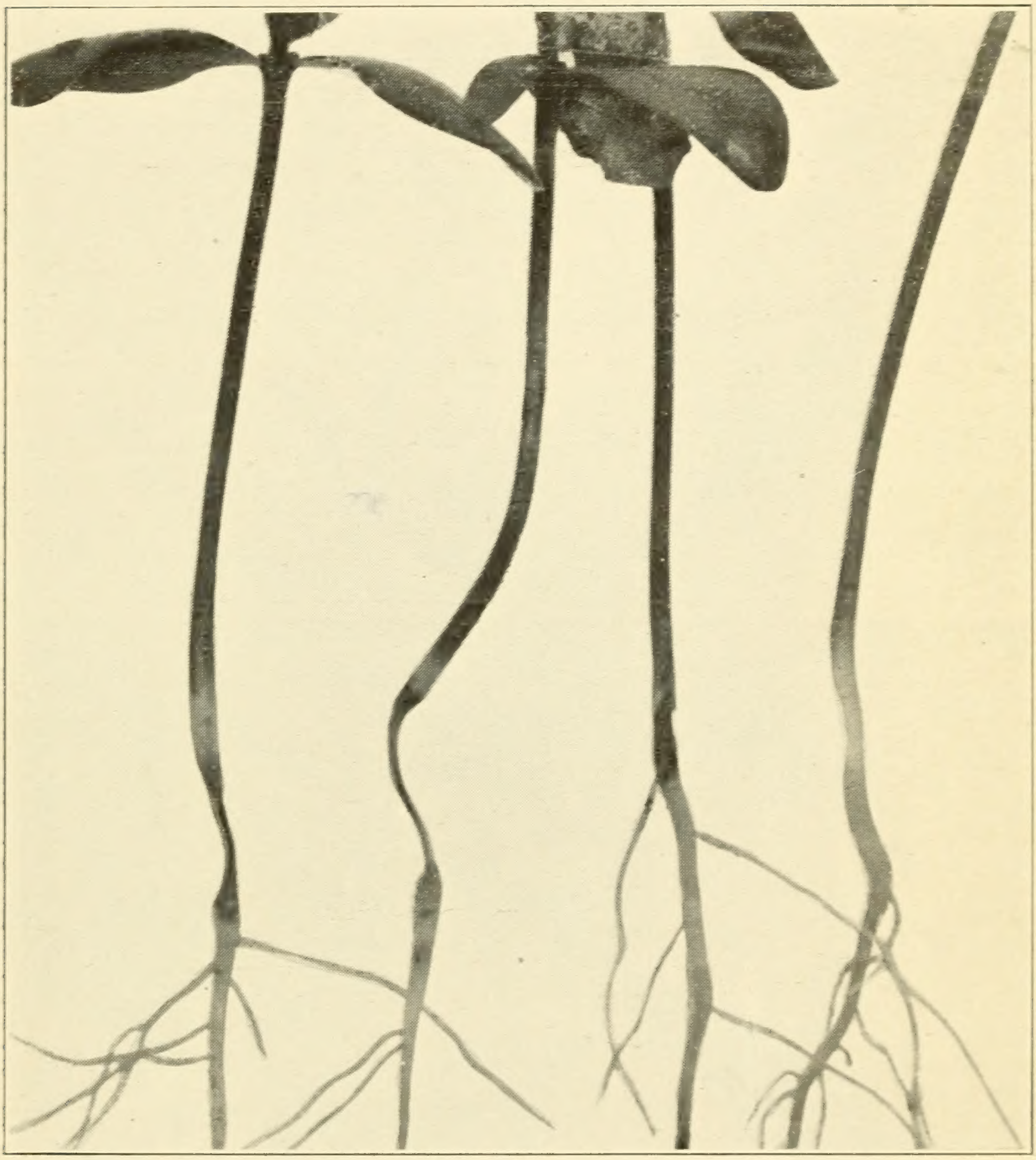
### FIELD OBSERVATIONS.

A number of observations had tended to indicate that excessive heat at the soil line during the seedling stage possibly was the cause of the trouble. For a number of years it had been noticed at Mandan, N. Dak., that flax cankered more in the nursery plats than in the rotation plats. In the former the rows were spaced rather widely, flax was sown rather thinly, and the plats were kept free from weeds. In the rotation plats the rows were closer together, the flax was sown more thickly, and weeds were allowed to grow. As a result of these two sets of conditions, the soil was much more exposed to the intense sunlight in the nursery plats than in the rotation plats. Indications pointed, therefore, to intense sunlight as being the most important factor in causing canker. Furthermore, for a considerable time it had been noted that flax canker had been most severe in flax on breaking (freshly turned sod), where weeds are practically absent and a thin stand usually occurs. By contrast, flax fields on old land usually are weedy. This canker, therefore, developed both in the nursery and in fields under similar conditions; that is, the most canker occurred where conditions made it possible for the intense sunlight to strike the bases of the young flax plants with the least interference from weeds and other flax plants. Likewise, in a series of experimental plats at Fargo, N. Dak., in 1917, in which the stand varied greatly because of variation in germination of seed, it was noted that the most flax canker resulted where the stand was thinnest. The results of these three sets of observations are summarized in Table 1.

TABLE 1.—*Summary of field observations of heat canker of flax on plats and under field conditions in 1917.*

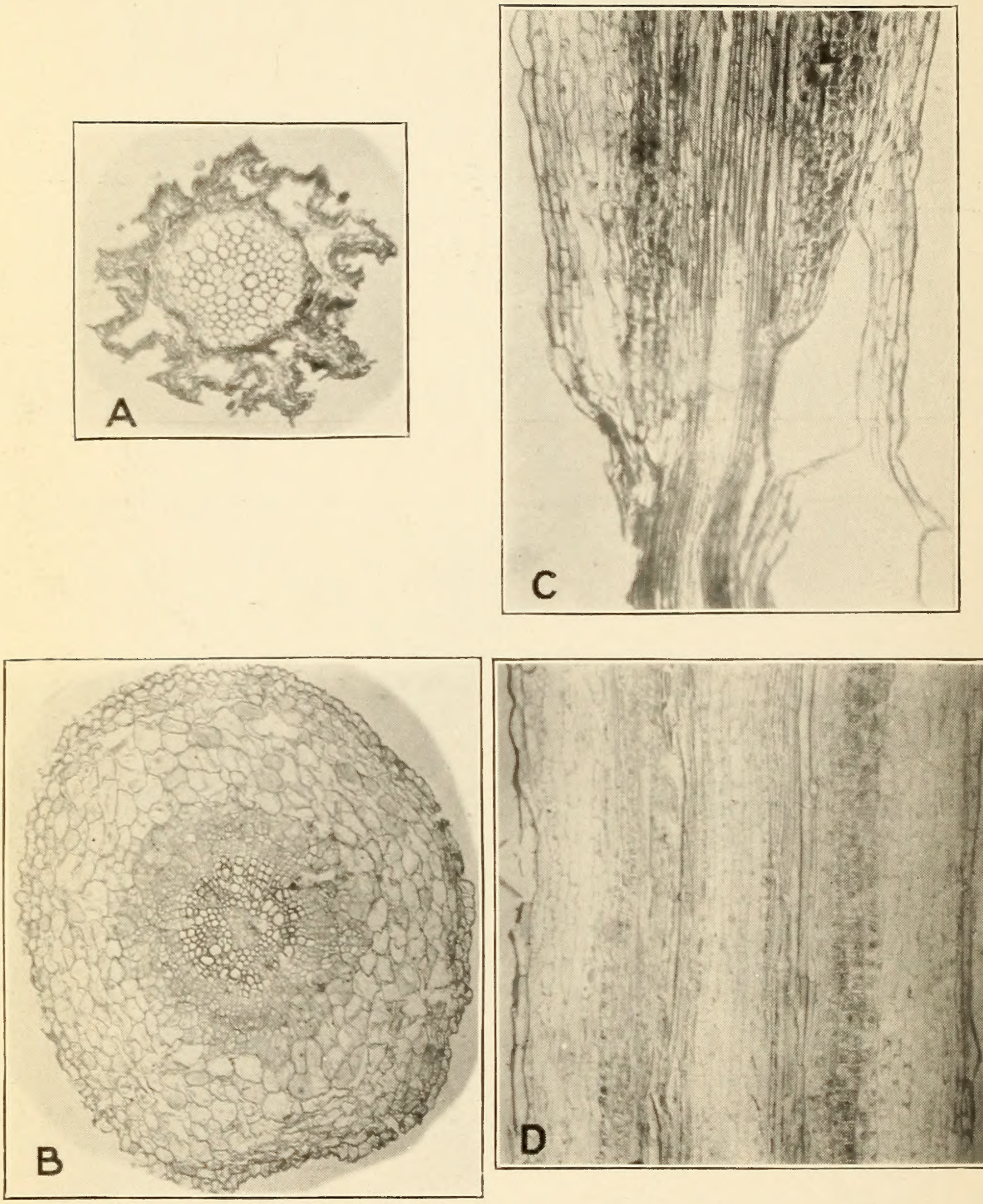
| Location and field condition. | Canker under different conditions. | |
|---|---|---|
| | Thin stand; no weeds. | Thick stand; weedy. |
| Mandan, N. Dak.: | | |
| Nursery plats | Canker abundant | |
| Rotation plats | | Canker slight or absent. |
| Farms: | | |
| Breaking (thin stand; few weeds) | Canker abundant | |
| Old land (thick stand; many weeds) | | Do. |
| Fargo plats: | | |
| Thin stand | Canker abundant | |
| Thick stand | | Do. |

These observations show that flax canker occurred most abundantly where the bases of the young flax plants and the adjoining soil were exposed to intense sunlight, on account of the thin stand and the absence of weeds.



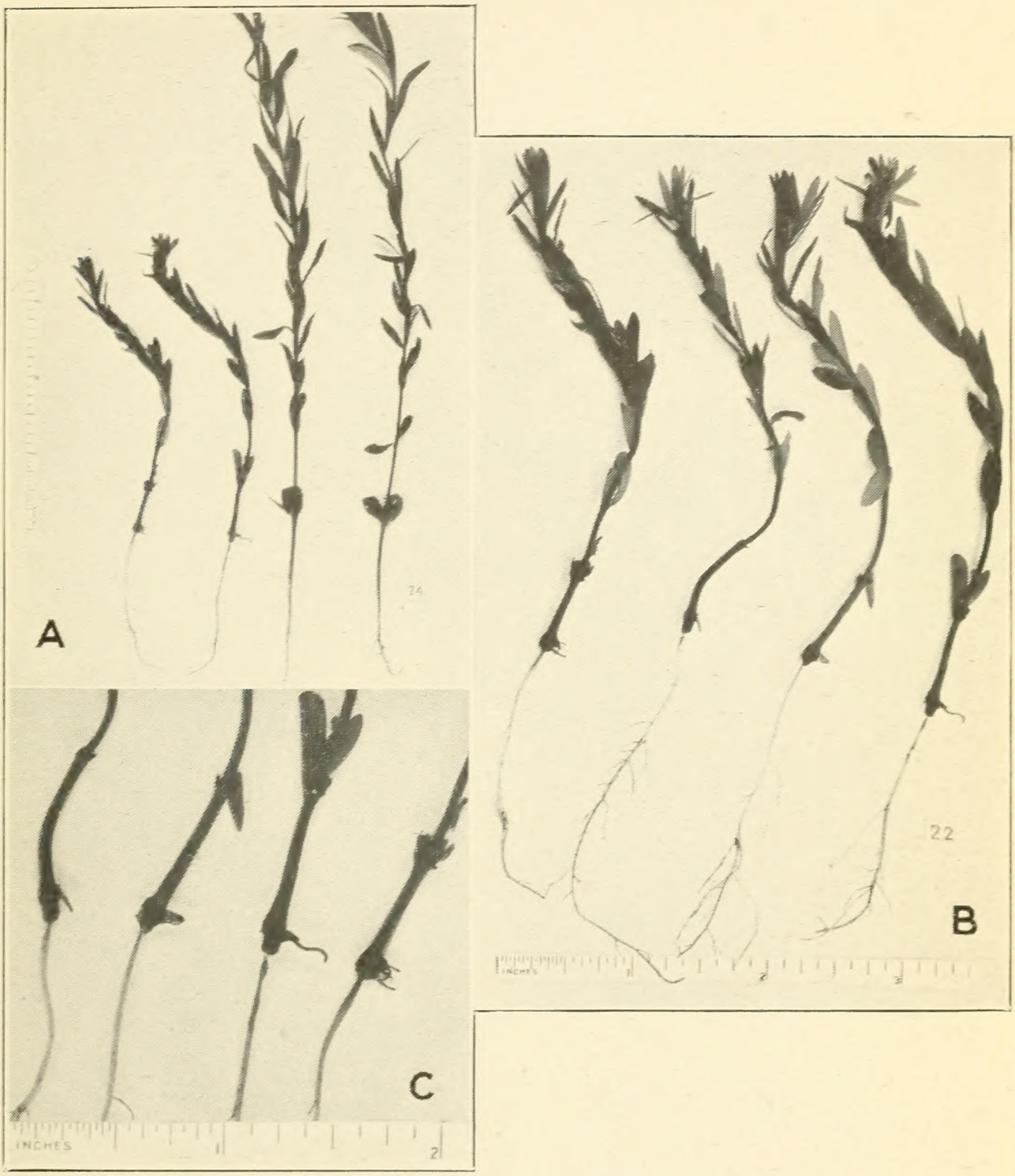
ANTHRACNOSE CANKER OF FLAX SEEDLINGS 33 DAYS OLD, RESULTING FROM ARTIFICIAL INOCULATIONS.

A healthy plant is shown at the right.



PHOTOMICROGRAPHS OF CROSS AND LONGITUDINAL SECTIONS OF STEMS OF HEAT-CANKERED FLAX PLANTS OF THE SAME AGE AS THOSE SHOWN IN PLATE III.

*A*, injured, constricted area of plant. This cross section shows the entire cortex destroyed. The cortical cells are broken down, but the stelar tissues are still functioning. There is no evidence of fungous mycelium in the injured tissues. Compare this with *B*. *B*, cross section immediately above the cankered area. All tissues appear healthy. Compare this with *A*. *C*, longitudinal section through the upper portion of an injured, constricted area. This shows the cortex destroyed in the cankered area. *D* longitudinal section of a young flax stem immediately above the heat-cankered area.



PLANTS FROM CANKER NURSERY G.

*A*, heat-cankered plants on the left; those on the right are not cankered. All four plants are of the same age. *B*, cankered plants as in *A*. *C*, the same plants as in *B*, enlarged to show the detail of the constricted areas and the enlargements just above these areas. Adventitious roots are starting at the soil line, on account of contact with moist soil. This does not occur when the soil is dry.

FIELD EXPERIMENTS.

During the latter part of the season of 1917 a shading experiment was conducted. The shade was provided by two pieces of canvas, each about 6 feet square, stretched horizontally about 3 feet from the ground above the young flax plants. In this experiment canker occurred in neither the shaded nor the unshaded area. However, the experiment did show that methods of shading which would reduce the light to a less degree were desirable. These investigations were temporarily discontinued during 1918.

In 1919 further experiments were planned and conducted to test the effect on young flax plants of intense sunlight and resulting heat at the soil line. Experiments were conducted also with a view to producing flax canker by artificial means.

Shading experiments were planned in which partial shade was provided by (1) strips of canvas, (2) cereal nurse crops, and (3) weeds. In these shading experiments the typical plat (Fig. 1) was 2

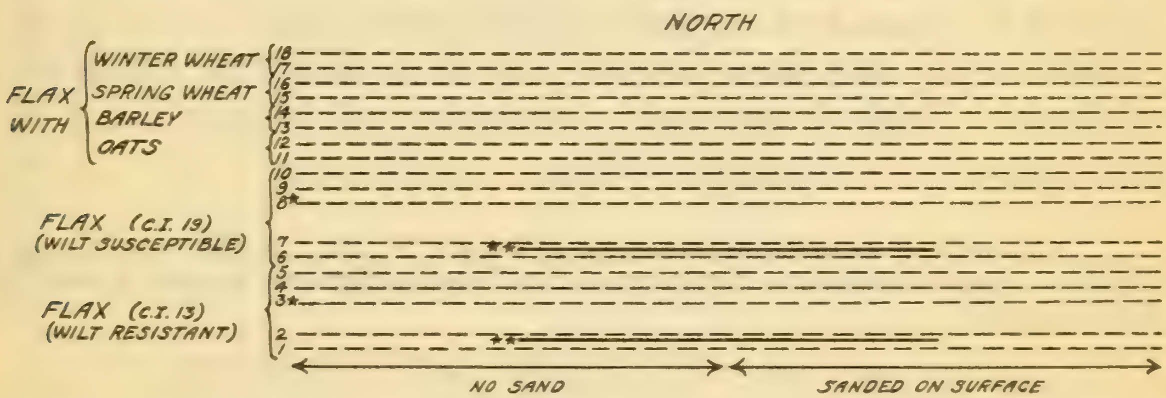



FIG. 1.—Plan of a typical plat in field experiments conducted at Fargo, N. Dak., in 1919, to determine the cause of flax canker of the nonparasitic type. Rows 3 and 8, marked with an asterisk (*), sown thinly at half the normal rate. Canvas strips 10 inches wide and 1 rod long were placed close to the flax rows marked with two asterisks (**) for shading from about 10 a. m. to 4 p. m., half on sanded area half on area not sanded.

rods long east and west and 10 feet wide north and south. It was divided into halves by a line extending north and south, and the soil of one of these halves was covered thinly with sand. The plat consisted of five rows each of two varieties of flax, North Dakota Resistant No. 114 (C. I. 13), a wilt-resistant variety, and Reserve (C. I. 19), a variety susceptible to wilt, and two rows each of flax with one of the cereals, oats, barley, spring wheat, or winter wheat, as a nurse crop. The rows extended east and west, so that each plant would be exposed to the sun's rays during the hottest part of the day and for the longest period possible. There was a 12-inch space between the second and third rows of each variety, and the third row of each variety was sown at half the usual rate. The other rows were spaced 6 inches apart. Half of the second row of each variety was shaded by placing just south of it vertical strip of canvas 10 inches wide and 1 rod long. By this mea s the young plants were shaded from about

10 a. m. to 4 p. m. This typical arrangement of plats is represented diagrammatically in Figure 1.

Experimental plats of the kind described were sown at Fargo on May 22 (plat A), June 9 (plat B), June 27 (plat C), and July 18 (plat D). In plat A the shades unfortunately were not put in position until after canker had occurred. Canker occurred in plat A, not in plat B, to a slight extent in plat C, and not in plat D. Similar plats were sown at Mandan, N. Dak., on April 28, June 11, and July 1, except that where sand was applied at Fargo the soil was compacted at Mandan. Dry weather, cutworms, and grasshoppers made the results at Mandan unworthy of consideration.

While the canvas shades unfortunately were not put in position in plat A at Fargo until after canker had occurred on June 16, the presence and absence of weeds in different parts of the plat served much the same purpose in varying the amount of shade. Rows 1, 2, and 3 had been carefully weeded, while the rest of the plat was rather weedy. It was at once strikingly evident that by far the most canker occurred where the young flax plants had not been shaded by weeds or by the nurse crops. The data from this experiment are given in Table 2, showing a summary and comparison of the percentages of canker under different conditions.

TABLE 2.—*Results of experiments conducted at Fargo, N. Dak., to determine the effect of various types of shading of flax in sanded and unsanded ground on plat A, sown on May 22, 1919.*

[Data on the occurrence of heat canker of flax recorded on June 18, 1919.]

| Conditions as to shading. | Without sand on surface. | | | | Surfaced with sand. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of plants in row. | Plants cankered. | | | Number of plants in row. | Plants cankered. | | |
| | | Number. | Per cent. | | | Number. | Per cent. | |
| | | | Actual. | Average. | | | Actual. | Average. |
| No shade: | | | | | | | | |
| Row No. 1 | 469 | 216 | 46.0 | 41.4 | 480 | 179 | 37.3 | 20.5 |
| Row No. 2 | 411 | 168 | 40.9 | | 467 | 80 | 17.1 | |
| Row No. 3 | 188 | 70 | 37.2 | | 277 | 21 | 7.6 | |
| Shaded by weeds: | | | | | | | | |
| Row No. 4 | 329 | 34 | 10.3 | 7.3 | 574 | 18 | 3.1 | 3.5 |
| Row No. 5 | 461 | 34 | 7.4 | | 433 | 17 | 4.0 | |
| Row No. 6 | 361 | 25 | 6.9 | | 198 | 10 | 5.1 | |
| Row No. 7 | 355 | 10 | 2.8 | | 159 | 6 | 3.8 | |
| Row No. 8 | 147 | 10 | 6.8 | | 80 | 2 | 2.5 | |
| Row No. 9 | 189 | 33 | 17.5 | | 288 | 7 | 2.4 | |
| Row No. 10 | 308 | 5 | 1.6 | | 115 | 4 | 3.5 | |
| Shaded by weeds and grain: | | | | | | | | |
| Row No. 11 | 637 | 19 | 3.0 | 4.3 | 333 | 0 | 0 | 1.9 |
| Row No. 12 | 352 | 16 | 4.5 | | 482 | 19 | 4.0 | |
| Row No. 13 | 390 | 10 | 2.6 | | 407 | 2 | .5 | |
| Row No. 14 | 379 | 11 | 2.9 | | 236 | 1 | .4 | |
| Row No. 15 | 322 | 40 | 12.4 | | 188 | 6 | 3.2 | |
| Row No. 16 | 396 | 9 | 2.3 | | 119 | 5 | 4.2 | |
| Row No. 17 | 348 | 8 | 2.3 | | 118 | 1 | .9 | |

Table 2 shows that under three different conditions of shade more canker occurred on the heavy dark soil than on the same type of soil which had been covered with yellow sand a quarter of an inch in depth. It also shows that canker occurred most abundantly where the soil was shaded the least. This holds true in general both where sand was applied and where it was not used.

As already stated, no canker occurred on the later sowings in plats B and D, and only a limited occurrence was noted in plat C, sown on June 27, where the canvas shades were placed, as shown in Figure 1. The data obtained from this plat, taken when the plants were about 4 inches high, are summarized in Table 3.

TABLE 3.—*Number of flax plants cankered under various conditions in plat C, at Fargo. N. Dak., sown on June 27, 1919.*

[Data on the occurrence of heat canker of flax recorded on July 18, 1919.]

| Row. | Shaded by canvas. | | Not shaded. | | Row. | Shaded by grain. | |
|---|---|---|---|---|---|---|---|
| | On sand. | No sand. | On sand. | No sand. | | On sand. | No sand. |
| No. 1 | ........ | ........ | 0 | 3 | No. 11 | 0 | 0 |
| No. 2 | 0 | 0 | 0 | 4 | No. 12 | 0 | 0 |
| No. 3 | ........ | ........ | 1 | 23 | No. 13 | 0 | 0 |
| No. 4 | ........ | ........ | 0 | 2 | No. 14 | 0 | 0 |
| No. 5 | ........ | ........ | 2 | 10 | No. 15 | 0 | 0 |
| No. 6 | ........ | ........ | 2 | 3 | No. 16 | 0 | 0 |
| No. 7 | ........ | ........ | 0 | 2 | No. 17 | 0 | 0 |
| No. 8 | ........ | ........ | 0 | 0 | No. 18 | 0 | 0 |
| No 9 | ........ | ........ | 0 | 0 | | | |
| No. 10 | ........ | ........ | 0 | 1 | | | |

It is evident from Table 3 that flax plants grown behind the canvas shades were not cankered, while some plants were cankered in the same rows when not shaded by the canvas, especially where sand was not applied. No flax was cankered where nurse crops were used. The row having the most cankered plants (No. 3) was the one sown thinly (at half rate) and double spaced from the next row on the south. While less canker occurred in this experiment, the results are in line with those obtained from plat A, presented in Table 2, in that the flax was cankered most where the soil was shaded least and where no sand was applied.

Experiments similar to those of 1919 were conducted during 1920, except that sand was omitted. A single variety resistant to flax wilt was used, and more variation was made in the rates of seeding. Six experimental plats were sown during the season at intervals of approximately two weeks. Canker appeared to a greater or less degree in the last four sowings. Plants emerging on May 28 or earlier were not cankered. The injury of plants in the plats where canker appeared occurred from 4 to 14 days after emergence. The data presented in Tables 4, 5, and 6 were obtained from the two plats in which cankered plants appeared in the greatest numbers.

Only traces of canker were observed in the other two plats. Table 4 shows the number of cankered plants occurring in rows sown at 3, 1.5, and 0.75 grams of seed per rod, with the rows spaced 10, 12, and 20 inches apart, respectively.

TABLE 4.—*Number of flax plants not cankered and cankered when grown in rows sown at three different rates and spaced differently at Fargo, N. Dak., in 1920.*

| Plat. | Number of plants in rod rows. | | | | | |
|---|---|---|---|---|---|---|
| | Sown 10 inches apart, 3 grams per row. | | Sown 12 inches apart, 1.5 grams per row. | | Sown 20 inches apart, 0.75 gram per row. | |
| | Not cankered. | Cankered. | Not cankered. | Cankered. | Not cankered. | Cankered. |
| Plat G-1 | 1,088 | 143 | 536 | 125 | 191 | 119 |
| Plat I-1 | 2,476 | 137 | 479 | 11 | 404 | 34 |
| Total | 3,564 | 280 | 1,015 | 136 | 595 | 153 |
| Cankered plants per cent | | 7 | | 12 | | 20 |

These data show that flax sown thinly cankered more than that which was sown thickly. This agrees with the results obtained in 1919, summarized in Table 3.

Table 5 presents data obtained in 1920 showing the influence of a nurse crop on the occurrence of flax canker. Barley was used as the nurse crop, and the flax was sown at the same rate as in the experiments without the nurse crop.

TABLE 5.—*Number of flax plants not cankered and cankered when grown without and with nurse crops, spacing and rate of seeding the same, at Fargo, N. Dak., in 1920.*

| Plat. | Number of plants in plat. | | | |
|---|---|---|---|---|
| | Without nurse crop. | | With nurse crop. | |
| | Not cankered. | Cankered. | Not cankered. | Cankered. |
| Plat G-2 | 1,088 | 143 | 1,084 | 86 |
| Plat I-2 | 1,611 | 121 | 1,600 | 3 |
| Total | 2,699 | 264 | 2,684 | 89 |
| Cankered plants per cent | | 9 | | 3 |

These data show that less canker injury occurs to flax plants when partially shaded by a nurse crop than when sown at the same rate without such protection.

The data presented in Table 6 show the effect of shading the young flax plants by 10-inch vertical strips of canvas used in the same manner as in 1919, the data for which were presented in Table 3.

TABLE 6.—*Number of flax plants not cankered and cankered in plats not shaded and partially shaded by canvas, at Fargo, N. Dak., in 1920.*

| Plat. | Number of plants in plat. | | | |
|---|---|---|---|---|
| | Not shaded. | | Partially shaded by vertical strips of canvas. | |
| | Not cankered. | Cankered. | Not cankered. | Cankered. |
| Plat G-3 | 813 | 80 | 560 | 0 |
| Plat I-3 | 282 | 20 | 181 | 0 |
| Total | 1,095 | 100 | 741 | 0 |
| Cankered plants ... per cent | | 8.4 | | 0 |

The results shown in Tables 3 and 6 are similar, in that flax plants grown behind canvas shades were not cankered, while some plants (8.4 per cent in 1920) were cankered in the same rows where not shaded by canvas.

It is to be regretted that apparatus was not at hand to take daily maximum soil-surface temperatures during the season of 1919. However, a limited number of soil-temperature readings were taken with ordinary thermometers. Six thermometers were placed under the various conditions in the plat and read at intervals. They were laid on the surface of the soil (or sand) and the bulbs barely covered with loose soil (or sand). The temperatures shown in Table 7 were taken on the same day at chosen places in the plat. Although the day was not one of the hottest of the season, it was hot enough to indicate the effect of shade and color of surface soil on soil-surface temperatures.

TABLE 7.—*Soil-surface temperatures, in degrees centigrade, taken in different parts of plat C, at Fargo, N. Dak., on July 18, 1919.*

| Thermometer. | Location. | Time of day. | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | A. M. | | | | P. M. | | |
| | | 8.30 | 9.30 | 10.30 | 11.30 | 1.00 | 2.00 | 3.00 |
| No. 1 | On sand, in row | 31 | 37 | 44 | 48 | 45 | 40 | 34.2 |
| No. 2 | On sand, between rows | 30 | 35 | 40 | 45 | 45.5 | 41 | 36 |
| No. 3 | On sand, shaded by canvas | 26 | 28 | 28.5 | 29 | 28 | 27 | 27 |
| No. 4 | On soil, in row | 32 | 36 | 44 | 49 | 46.5 | 42 | 36 |
| No. 5 | On soil, between rows | 33 | 39 | 44 | 49 | 47 | 43 | 37 |
| No. 6 | On soil, shaded by canvas | 27 | 29 | 29 | 31 | 28 | 28 | 27.5 |

The data given in Table 7 and presented graphically in Figure 2 show that the rate of change of soil-surface temperatures on a hot day is much less rapid in the shade of a canvas 10 inches in height than on soil surfaces exposed directly to the sun's rays. This

explains why no canker occurred in those portions of the rows of young flax plants shaded by the vertical strips of canvas, while at the same time some plants were cankered in the portions of the rows not so shaded.

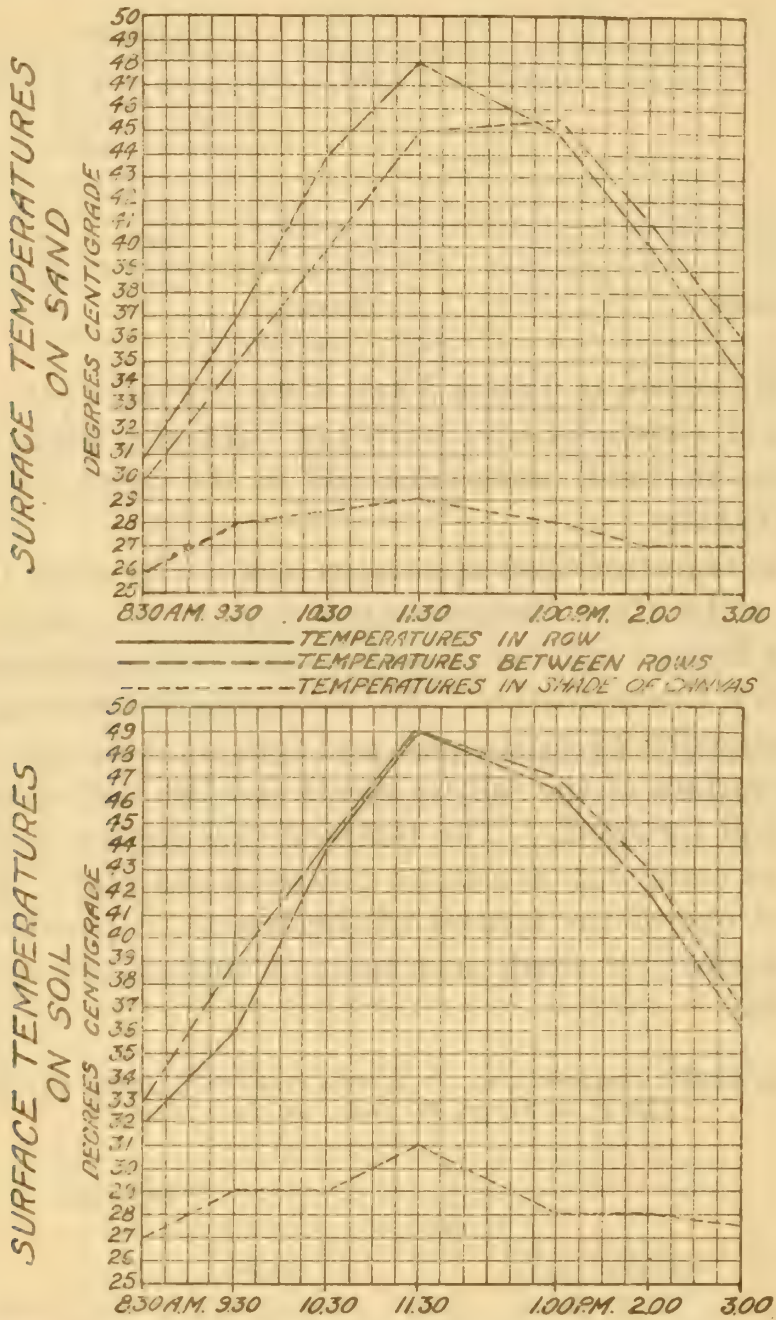



FIG. 2.—Diagram showing the variations in soil-surface temperatures in different parts of plat C at Fargo, N. Dak., on July 18, 1919.

Table 7 also shows that higher soil-surface temperatures occurred where the heavy dark soil had not received a surface application of light yellow sand. This probably explains why more canker occurred in the portions of the plats where sand had not been applied, as shown by the data in Tables 2 and 3.

On July 18, 1919, when the soil-surface temperature data shown in Table 7 were taken, the sun shone brightly until 2.30 p. m., when it became obscured by clouds. About 4 o'clock it began to rain. Previous to this the soil was fairly dry.

The temperature records for the seasons of 1920 and 1921 (Table 8 and Figs. 3 and 4) were taken with a soil thermograph the bulb

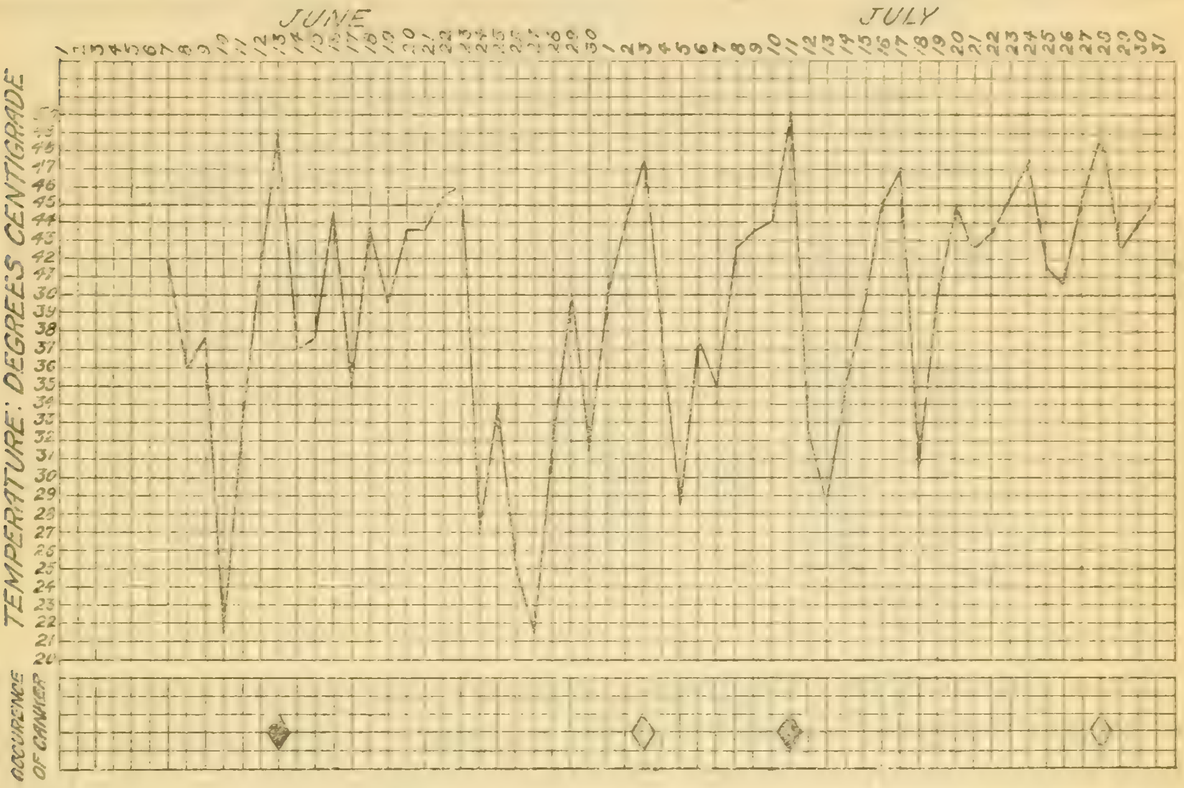



**Fig. 3.**—Diagram showing the daily maximum soil temperatures at a depth of half an inch, as recorded by a soil thermograph with bulb barely covered, at Fargo, N. Dak., during June and July, 1920 (see Table 8). The black diamonds show times when severe canker occurred and the white diamonds times when canker was slight.

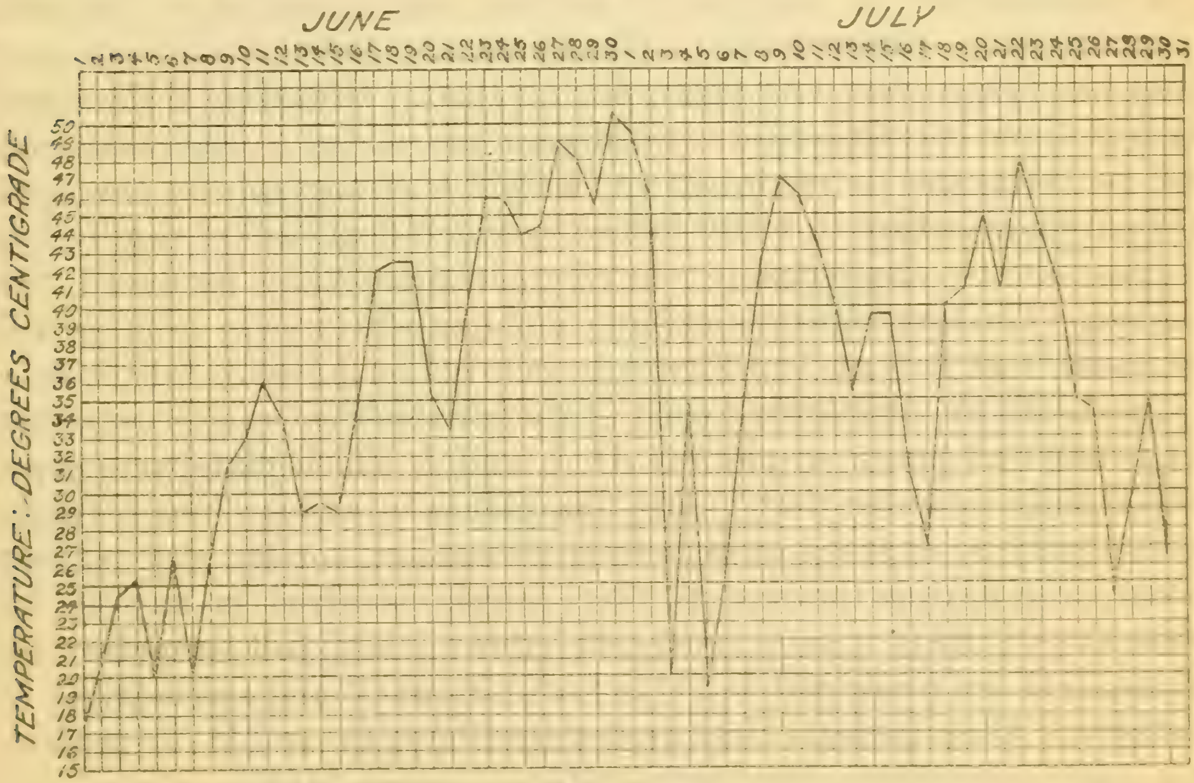



Fig. 4.—Diagram showing the daily maximum soil temperatures at a depth of half an inch, as recorded by a soil thermograph with bulb barely covered, at Fargo, N. Dak., during June and July, 1921 (see Table 8).

of which was buried in the surface inch of soil. No plants were allowed to grow within 4 feet of the bulb. This thermograph recorded the soil temperature at a depth of approximately half an inch.

TABLE 8.—*Daily maximum soil temperature in the heat-canker plat at Fargo, N. Dak., in June and July, 1920 and 1921.*

[Data in degrees centigrade, as recorded by a soil thermograph with the bulb barely covered, which corresponds to the soil temperature at a depth of half an inch.]

| Day of month. | 1920 | | 1921 | | Day of month. | 1920 | | 1921 | |
|---|---|---|---|---|---|---|---|---|---|
| | June. | July. | June. | July. | | June. | July. | June. | July. |
| 1 | ........ | 40.0 | 17.5 | 49.5 | 17 | 35.0 | 47.0 | 42.0 | 27.0 |
| 2 | ........ | 44.0 | 20.5 | 46.0 | 18 | 43.5 | 30.5 | 42.5 | 40.0 |
| 3 | ........ | 47.5 | 24.5 | 20.0 | 19 | 39.5 | 40.0 | 42.5 | 41.0 |
| 4 | ........ | 37.5 | 25.5 | 35.0 | 20 | 43.5 | 45.0 | 35.5 | 45.0 |
| 5 | ........ | 28.5 | 20.0 | 19.5 | 21 | 43.5 | 42.5 | 33.5 | 41.0 |
| 6 | ........ | 37.5 | 26.5 | 25.5 | 22 | 45.5 | 43.5 | 40.0 | 48.0 |
| 7 | 41.5 | 35.0 | 20.0 | 35.0 | 23 | 46.0 | 45.5 | 46.0 | 44.5 |
| 8 | 36.0 | 42.5 | 26.5 | 42.5 | 24 | 27.0 | 47.5 | 46.0 | 42.0 |
| 9 | 37.5 | 43.5 | 31.5 | 47.0 | 25 | 34.0 | 41.5 | 44.0 | 35.0 |
| 10 | 21.5 | 44.0 | 33.0 | 46.0 | 26 | 25.0 | 40.5 | 44.5 | 34.5 |
| 11 | 33.0 | 50.0 | 36.0 | 43.5 | 27 | 21.5 | 45.5 | 49.0 | 24.5 |
| 12 | 41.0 | 32.5 | 34.0 | 40.0 | 28 | 32.0 | 49.0 | 48.0 | 29.5 |
| 13 | 49.0 | 28.5 | 29.0 | 35.5 | 29 | 40.0 | 42.5 | 45.5 | 35.0 |
| 14 | 37.0 | 35.0 | 29.5 | 39.5 | 30 | 31.5 | 44.0 | 50.5 | 26.5 |
| 15 | 37.5 | 39.5 | 29.0 | 39.5 | 31 | ........ | 45.5 | ........ | ........ |
| 16 | 44.5 | 45.0 | 34.5 | 31.0 | | | | | |

Data obtained in 1921 from maximum thermometers having the bulbs painted green showed that the soil-surface temperatures on hot days were considerably higher than the soil temperatures at the depth of half an inch. On the hottest days, that is, on June 27, June 30, and July 9, the soil-surface temperatures recorded by the maximum thermometers were respectively, 7, 4.5, and 7 degrees higher than the temperatures at a depth of half an inch recorded by the soil thermograph. Unfortunately, checks on the soil-thermograph records like these were not taken during 1920. However, if the averages of these corrections are transferred and added to the maximum soil temperatures as recorded by the soil thermograph on the days of high temperature in 1920, following which heat canker resulted, it is possible to approximate the temperatures that produced the canker. The four highest maximum soil temperatures in 1920, as will be noted from Table 9 and Figure 3, occurred on June 13, July 3, July 11, and July 28. Following each of these dates heat canker occurred on young flax plants in plats G, H, I, and J, which plats were sown periodically in order that young flax plants in at least one of these plats would be exposed at high temperatures on the hot days at any given time during the season. No canker occurred in any of the plats except the four mentioned and following high soil temperatures. These data are presented in Table 8 and Figure 3 and summarized in Table 9. They indicate that under conditions favorable for producing heat canker the critical temperature is about 54° C.

As shown in Table 9, only a few plants cankered in plats H and J, while many plants cankered in plats G and I (Table 4). In plat H the lack of severe injury probably was due to the fact that relatively old plants were subjected to comparatively low temperatures. Prob-

ably no canker would have occurred in this plat if the high temperature had not been preceded by a protracted period of wet, cloudy weather. This caused a somewhat succulent growth and also compacted the soil. In plat J the lack of severe injury probably was due to the fact that the plants were growing under hot, dry conditions and were not as succulent as the plants in the other plats in which canker occurred.

TABLE 9.—*Soil temperatures and severity of heat-canker injury produced on young flax plants at Fargo, N. Dak., on the four hottest days during June and July, 1920.*

| Plat. | Number of days after plants emerged. | Date cankering occurred. | Maximum soil temperatures when canker occurred (° C.). | | Average percentage of canker. |
|---|---|---|---|---|---|
| | | | Thermograph record at a depth of half an inch. | Approximate soil-surface temperature. | |
| Plat G | 8 | June 13 | 49.0 | 55.2 | 23.3 |
| Plat H | 14 | July 3 | 47.5 | 53.7 | Trace. |
| Plat I | 4 | July 11 | 50.0 | 56.2 | 4.7 |
| Plat J | 9 | July 28 | 49.0 | 55.2 | Trace. |

In 1921 the investigations were continued in a similar manner both at Fargo and at Mandan, N. Dak. However, as will be seen in Table 8 and Figure 4, high soil temperatures did not occur until late in June, and therefore little, if any, flax canker developed before that time. Likewise, following the high soil temperatures in the last days of June and early July, but little canker developed, even though the soil-surface temperatures were sufficiently high to expect the production of canker in the late sowings. No doubt the lack of canker production under these conditions is chargeable to a combination of several factors, both from the standpoint of the condition of the young plants on the one hand and their environment on the other. Plants which had grown during the hot, dry weather of the latter part of June and early July were apparently not sufficiently succulent to be susceptible to canker injury from the high soil-surface temperatures. The soil throughout this period also was dry and unusually mellow, without any crust, and this also may have had some effect on the conditions governing the production of canker. It may be added that when the surface soil is mellow little air pockets tend to form immediately about the plants, in contrast to the close contact of the soil surface with the plant stems which occurs when the fine soil surface is compacted by rains and a thin crust is formed.

The soil crust caused by rains brings the surface soil in immediate contact with the tender surfaces of the succulent young flax stems. Injury results when such surface layers in immediate contact with the tender living tissues reach the high temperatures. This surface

crust may act as a conductor of heat to the plant. In contrast with this condition, when the top layer of the soil is mellow, which was the condition in late June, as previously pointed out, the little air pockets about the young plant stems tend to act as insulators and protect the stems from the high temperatures.

The evidence, therefore, indicates that heat canker of flax results from a combination of succulence in the young plants and high temperatures of the surface soil in immediate contact with such succulent tissues.

### ARTIFICIAL PRODUCTION OF NONPARASITIC CANKER.

A cankered condition very similar to heat canker also has been produced artificially on flax. As agents, both chemicals and heat were used. On July 11, 1919, 50 plants (C. I. 191) were slightly burned at the soil line with concentrated sulphuric acid At various intervals, from one to five minutes, the acid was washed off with water. Most of the plants died when the acid was left on as long as five minutes. By July 24 typical heat canker had developed on 17 of the plants that remained alive.

On July 20, 1919, the surface soil around seven flax plants was artificially heated. The flax plants were grown in pots and were 20 days old. A heavy aluminum wire about 14 inches in length was bent to form in its center a circular loop about 1 inch in diameter. The remainder of the wire led from this circle in two parallel adjoining strands. The circle of wire was placed in turn over each of the seven plants and buried slightly in the soil at the base of each plant in such a way that the plant was in the center of the loop. The flame from a Bunsen burner was applied to the ends of the wire until enough heat to produce injury was conducted by the wire to the soil immediately surrounding the plant. In about eight days a few of these plants showed typical heat canker.

On July 29, 1919, 12 young flax plants were slightly injured by electrically heated wire. A loop of fine copper wire was placed around each plant, barely touching the stem at the soil line, and an electric current (110 volt, alternating) was passed through it. The wire was immediately burned out, but the heat for the instant was sufficient to cause slight injury. One flax plant of the twelve showed typical heat canker on August 7.

### SIMILAR INJURY TO OTHER PLANTS.

Similar maladies have been described or observed on various plants. In one instance the senior writer noted in a field of buckwheat in central Montana a malady similar to heat canker of flax. The buckwheat plants having the most typical symptoms were in a portion of the field where the stand was thin. Later examination showed no evidence of fungous attack.

At Fargo, N. Dak., about June 10, 1921, the junior writer and Prof. H. L. Bolley observed similar injuries on wheat and barley seedlings. Similar injuries were reported also about the same time from other parts of North Dakota on these crops and also on oats. (For soil temperatures, see Fig. 4.)

Hartley (*7* and *8*) described basal lesions due to excessive heat on seedlings of conifers, rye, and cowpeas. He found that the surface layer of the soil in a Nebraska nursery attained a temperature of 52° C. even in the half-shade of a lath frame. The very young conifer seedlings were injured at the soil surface, where a constriction formed. Later they fell over and died. The lesions usually became white, and for this reason he called the trouble white-spot.

MacMillan and Byars (*10*) observed a heat injury to beans in Colorado. The stems were shrunken at the ground line, and many of the young plants fell over.

Münch (*12*, *13*, and *14*) reported soil-line heat injury on maple, vetch, and peas and thought that in some cases germinating seeds, as well as seedlings already emerged, are killed by overheated soil. The death point for vegetative plant cells, according to Mayr (*11*) and Münch, lies at 54° C. Münch records a soil-surface temperature as high as 62° C. in sandy soil and states that temperatures of 50° to 55° C. are reached almost daily in such soils during clear weather. Schuster (*20*) found a stem girdling of young plants in German East Africa which corresponds very closely to descriptions of heat injury by Münch and Tubeuf (*21* and *22*).

Ramann (*17*) has seen large numbers of year-old oaks killed off by heat girdling in the steppes of south Russia and has recorded there soil-surface temperatures higher than 60° C.

Hartig's (*6*) temperature measurements of a spruce in August show how much the parts of plants are warmed above the air temperatures. A temperature of 55° C. was found in the cambial region of the southwest side when the air temperature was 37° C.

Mayr (*11*) states that free-lying soil, especially if dark colored, as is the case when it is rich in humus, can attain high temperatures. He found the maximum temperature to be 68° C. In another case he found a temperature of 58° C. at 49° latitude and at an elevation of 1,870 feet.

Tubeuf reports soil-surface temperatures above 60° C. in the United States.

## PREVENTIVE MEASURES.

Assuming that the consistent losses from flax canker in the semiarid northern section of the Great Plains area are due to excessive heat, any remedial measures would be in the nature of practices which would prevent the overheating of the surface layer of the soil during the seedling stage or would bring the plant past the stage of

susceptibility to injury before the excessive heat occurs. Investigations along these lines are being continued by the Office of Cereal Investigations in cooperation with the North Dakota Agricultural Experiment Station. Tentative suggestions for lessening this injury are (1) higher rates of seeding, (2) earlier dates of seeding, and (3) drilling north and south rather than east and west. In this connection it is well to remember that the beginning of these intermittent periods of overheating in this section usually occurs in the first or second week of June.

## SUMMARY.

Investigations have shown that the cause of the heat-canker type of flax injury is nonparasitic in its nature.

It occurs somewhat uniformly each year in the northern Great Plains area and causes a marked loss in flax production.

The cortex of the stem is killed at the surface of the ground. Sooner or later the cankered plants topple over. Young cankered plants die at once, while those that are a little older may remain alive for days or weeks, as long as the vascular systems function. Stems of the older cankered plants usually enlarge just above the injury, and sometimes also just below it. The result is a girdling of the plants at the soil line.

In these experiments and observations flax was cankered only during and immediately following very hot days. Flax plants when more than 4 inches high are only slightly susceptible. Flax plants which have developed under hot, dry conditions are less susceptible to injury from high soil-surface temperatures than more succulent plants.

Flax plants which are grown in a soil having a shallow surface mulch over a firm seed bed are less readily injured than those grown in a soil in which the surface layer has been compacted into a crust by rains. Plants shaded by a vertical strip of canvas 10 inches high were not cankered, while many unshaded plants in the same row were cankered. Thinly sown flax was cankered more than thickly sown flax.

Flax sown with cereals as nurse crops was cankered comparatively little, and flax with weeds was cankered less than flax free from weeds.

Evidence indicates that heat canker of flax results from a combination of succulence in the young flax plants and high temperatures of the surface soil in immediate contact with the succulent stem tissues.

Killing the cortex of young flax plants by artificial heat produced typical heat canker.

Promising control measures seem to be thicker seeding and early sowing, and possibly drilling rows north and south instead of east and west may prove helpful in lessening the severity of canker injury.

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